Helsinki Studies in Education, number 60

Yan Wang

Restructuring science curriculum for the Twenty-first Century

An assessment of how scientific literacy and twenty-first century competencies are implemented in the Finnish and Chinese national primary science curricula

To be presented, with the permission of the Faculty of Educational Sciences of the University of Helsinki, for public discussion in the Sali 107 of Athena, Siltavuorenpenger 3A, on Friday, 29th of November 2019, at 12 noon.

Helsinki 2019

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Unigrafia, Helsinki

ISBN 978-951-51-5583-2 (printed version)
ISSN 1798-8322
ISBN 978-951-51-5584-9 (pdf-version)
ISSN 2489-2297

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An assessment of how scientific literacy and twenty-first century competencies are implemented in the national primary science curricula in Finland and China

Abstract
The dissertation reports on how the national primary science curricula in Finland and China (a) specifies the objectives of scientific literacy, and (b) has adopted the concept of twenty-first century competencies.

Globalization has influenced education. The goals of science education have been evolving with the changes in the connotation of scientific literacy. The goal of developing competencies for the twenty-first century has been written in policy documents at national and international levels. The phenomenon indicates convergent changes in education: from knowledge-centered education to competencies-focused, indicating alignment with sustainable development goals for education. However, problems and challenges arise at the same time as the convergent reforms of education.

Both scientific literacy and 21st-century competencies could be merely an interesting term in policy documents rather than a consistent and deliberately chosen goal. Given that scientific literacy and 21st-century competencies are abstract terms, the interpretation of the goals that have been given the same names may vary in policies. The differences should affect the results of the implementation of reforms. How to teach 21st-century competencies within traditional subjects such as science has been the biggest challenge in schooling. The traditional Anglo-American curriculum seems to be not enough for designing a curriculum in response to the trends in educational reform, but the European-Scandinavian *Bildung-Didaktik* may serve as an alternative for curriculum design.

In this research, the national primary science curricula in Finland and China were analyzed following the deductive content analysis process via two conceptual frameworks: the scientific literacy framework (PISA-derived framework) and the 21st-century competencies framework (revised Assessment and Teaching of 21st Century Skills framework, ATC21S). The discussion draws on two theoretical perspectives: the different visions of competencies in science as well as generic competencies; and the Anglo-American curriculum tradition and the European-Scandinavian *Bildung-Didaktik* tradition.

The study found that both countries' science curricula emphasized the goal of scientific literacy with the integration of learning and applying knowledge in science (Vision I and Vision II). However, the Chinese curriculum is emphasized more on knowledge of science (Vision I) compared to the Finnish one, and in line with the traditional Anglo-American curriculum. The Finnish curriculum has explicitly shown the emphasis on learning and applying knowledge of science in daily contexts (Vision II). Nevertheless, the critical perspective on socioscientific issues (Vision III) is not written explicitly. The Finnish curriculum demonstrates an affiliation with the tradition of *Bildung-Didaktik*; some of the 21st-century competencies have been illustrated as an end of education through the learning of subject matter in science.

It is argued in the dissertation that science education is both a goal in itself and a means of achieving the goals of 21st-century competencies. A science curriculum should be organized with its objectives related to subject matters based on Anglo-American curriculum tradition and with the guidance of *Bildung*. The PISA and ATC21S frameworks can be applied for either guidance of curriculum design or a tool to examine the actualization of a curriculum.

Keywords: science curriculum, comparative study, scientific literacy, twenty-first century competencies

Acknowledgments

The work for the dissertation has been supported by the Chinese Scholarship Council for four years. I also acknowledge the Doctoral School in Humanities and Social Sciences at the University of Helsinki for their financial support (the thesis completion grant and travel grants). The National Association for Research in Science Teaching (NARST) and the European Science Education Research Association (ESERA) are also gratefully acknowledged for their support to enable me to participate in the Sandra K. Abell Institute for Doctoral Students 2017 and the doctoral summer school 2018. It would not have been possible to finish this dissertation without the support and guidance that I received from many people.

I would like to express my gratitude to my supervisors. Without the guidance and constant feedback from you both, this PhD would not have been achievable. To Professor Kirsi Tirri, thank you for your advice on research and career. You have taught me how to be more productive and let me know more about academia. I could not have finished this doctoral study in time without your encouragement. Thank you for including me in the doctoral seminar and other events. The work would not have been possible without support from Professor Jari Lavonen. Your advice on research and your support by including me in a range of science education events has been invaluable. I sincerely appreciate all of these. Thank you for all your help and encouragement for my research ideas.

I would like to acknowledge my pre-examiners, Professor Tuula Keinonen and Professor Josef de Beer. Thank you for your valuable work and suggestions for improving the thesis. I also wish to thank Professor Stefan Hopmann for agreeing to be the opponent.

I would like to thank the anonymous peer reviewers of the three papers that make up part of this dissertation. I also would like to thank the language editors from the Language Centre at the University of Helsinki.

I would also like to offer my deepest thanks to my doctoral colleagues in the Faculty of Educational Sciences. Thank you for all the discussions and emotional support. I also would like to thank Sirkka Ahonen; your valuable pieces of advice for the research and career are helpful. Your attitudes to life and your energetic way of working encourage me.

I would thank my master's degree supervisor, Professor Yimin Gao. Thank you for your unconditional trust. I would like to thank Professor Bangping Ding for sharing the original document of the Chinese science curriculum. I would also like to express my gratitude to Professor Ralph Levinson, Dr. Elina Kuusisto, Dr. Katriina Maaranen, Professor Sibel Erduran, Professor Su Xiao, Professor Xiaoyi Gao, Professor Jun Teng, and Professor Yuzhuo Cai.

I would thank my friends in Finland. I appreciate the friendship, and it is a treasure in my life. Thank you Yanling, Ziyu, Auli Saarinen, Haiqin, Heidi, Nasibeh, and Xixi, just to name a few here. I never felt lonely when in your company. Thank you for the friends from the MMM and Brighten Up groups, Wenzhong, Ben, Xiaoxu, and Xun. You are the best company forever and ever. Thank you, the lovely couple, Wendan and Xin, with whom your friendship started in Jyväskylä. Thank you, my best friend Gaoming from Tampere. Thank you to my dear friends, who moved abroad from Finland, Yurui, Ying-Hsien, Bin, Zhenxing, Ronghua Liang, Yuan, Juan, and Siiri Turunen, just to name a few here. Activities and conversations with you guys have enriched my life.

Lastly, I would like to thank my parents for all their love and encouragement. You gave me the freedom to pursue my interests. This dissertation would not have been possible without your unwavering and unselfish love and support given to me at all times. Love you!

The doctoral study journey is coming to an end, which is a unique and unforgettable experience, a mixture of hope, enjoyment, frustration, and love. This PhD is part of my life and constitutes the current “me.” I can start my ventures in a new journey with the “license,” even if in my eyes this PhD has never merely been a degree.

Learning Centre Aleksandria, Helsinki, September 3rd, 2019
Yan Wang
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Contents

List of original publications

The thesis consists of a summary and the following publications (Studies I-III):

I Study I: Wang, Y., Lavonen, J., Tirri, K. (2019). An assessment of how the scientific literacy-related objectives are actualized in National Primary Science Curricula in China and Finland. *International Journal of Science Education*. *International Journal of Science Education, 41*(11), 1435-1456. DOI:10.1080/09500693.2019.1612120

II Study II: Wang, Y., Lavonen, J., Tirri K (2019). Twenty-first Century Competencies in the Chinese Science Curriculum. In X. Y. Du, H. Q. Liu, A. A. Jensen, F. Dervin (Eds.), *Nordic-Chinese Intersections on Education* (in press). Palgrave MacMillan.

III Study III: Wang, Y., Lavonen, J., Tirri, K. (2018). Aims for Learning 21st Century Competencies in National Primary Science Curricula in China and Finland. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(6), 2081-2095. https://doi.org/10.29333/ejmste/86363

1. Introduction

The aim of the research in this article-based dissertation is an attempt to 1) conceptualize and examine two concepts, i.e., scientific literacy and twenty-first century competencies, 2) investigate how the current Chinese and Finnish national primary science curricula specify the objectives of scientific literacy and have adopted the concept of 21st-century competencies as a part of the curricula. The research considers the question of whether it is possible and prudent to design a scientific literacy specified framework (standard) which integrates the concept of 21st-century competencies based on the theories of the curriculum.

Scientific literacy has become a widely acknowledged goal in science education since the 1950s (DeBoer, 2011; Hodson, 2011). The concept has gained popularity in several countries' national science curricula after its application as a core concept in the Program for International Student Assessment (PISA) (Roberts & Bybee, 2014). Scientific literacy typically signals the changes of emphasis from knowledge-oriented with a focus on the canonical subject matters of the natural sciences (Vision I) to competency-oriented centering on the application of knowledge and skills in science-related situations (Vision II) (Roberts, 2007; Roberts & Bybee, 2014). Until the last few decades, the two visions of scientific literacy have been problematized with a concern about the taken-for-granted discourse of neoliberalism in science education (Hodson, 2003; Levinson, 2010; Sjöström, Frerichs, Zuin & Eilks, 2017). After that, critical scientific literacy or Vision III has been explicitly noted. Nevertheless, little of the research in the field of science education has discussed the ideological assumptions that underpin the globalized aim described as "scientific literacy" in the policy documents (Carter, 2005; Carter, 2008; Fensham, 2009; Levinson, 2010; Lin, Lin, Potvin & Tsai, 2019).

Responding to the growing demands from labor markets in the knowledge society, education reforms have been ongoing; there have been reforms in teaching and learning subjects as an end in itself, to a goal to cultivate transferable competencies. Twenty-first century competencies is the concept demonstrating the trend. Twenty-first century competencies or as described in alternative terminologies, such as "key competencies," "generic competence," "core skills," was first emerged in policy documents from supranational organizations and have after that been borrowed by many countries (Voogt & Roblin, 2012). The European Union (EU), the United Nations Educational, Scientific and Cultural Organization (UNESCO), and the Organization for Economic Co-operation and Development (OECD) are some of the major supranational institutions that have published numerous policies regarding the schooling of 21st-century competencies. After these organizations, countries including the United States, China, Finland,

and Singapore have declared the need to implement education reforms, beginning with the publication of various frameworks concerning 21st-century competencies. However, there are many challenges in actualizing the goals of 21st-century competencies.

The convergence of the goals of scientific literacy and 21st-century competencies worldwide is doubtful due to the reasons as follows. First, the global process of designing science curricula with 21st-century competencies in mind, in fact, is not a one-way process. It is a (re)contextualizing process of the adoption of worldwide recognized concepts, e.g., scientific literacy and 21st-century competencies, at the national level, a process is described as "glocalization" (Ball, 1998; Roudometof, 2016). The process begins with policymakers who borrow educational concepts either from other countries, mainly from reference countries, who perform well in international assessments in science, such as Finland and China (Shanghai), or from supranational organizations, such as the OECD (Schriewer & Martinez, 2004; Sellar & Lingard, 2013; Steiner-Khamsi, 2003). However, if the concepts borrowed from foreign areas or supranational organizations are adopted in an abstract way at national level, they can merely be applied as attractive terms in national policy documents rather than as consistent and deliberately-chosen goals for educational reforms (DeBoer, 2011; Grek, 2009; Sadler & Zeidler, 2009; Sellar & Lingard, 2013; Steiner-Khamsi, 2012; Takayama, 2010). Second, policies at a national level are the outputs of conflicts, tensions, and compromises with respect to cultural, political, and economic considerations (Cuban, 1992; Steiner-Khamsi, 2012; Takayama, 2010). Policymakers do not merely attempt to learn from others for the end of globalization in education, but to justify the education reform interests for their own sake. Third, the two concepts, i.e., scientific literacy and 21st-century competencies, are complex and evolving. Namely, as mentioned previously, there are at least three visions of scientific literacy. The concept of 21st-century competencies derived from policy documents is further unclear than the concept of scientific literacy. The vagueness is not only owing to the variance of terminologies used to present it, but also because of the lack of clarity of its connotation and constitution (National Research Council, 2012; Reimers & Chung, 2016). More importantly, Willbergh (2015) argues that the concept "competence (competency)" has been struggling with theoretical problems, because neither is it originally an educational concept, nor has enough research confronted the concept with traditional educational concepts. Consequently, scientific literacy and 21st-century competencies may suggest different meanings in a range of policy documents. Chapter 3 will briefly revisit the concepts of scientific literacy and 21st-century competencies.

A comparative perspective will be beneficial to inquire about the implementation of the concepts of scientific literacy and 21st-century competencies in science curricula. Such a perspective of the inquiry helps us to understand better the status of the implementation of the concepts in different countries' science curricula. In return, an examination of science curricula in countries having different educational traditions may broaden views on the design of an international standard of science. In particular, according to research in science education and curriculum studies, another curriculum tradition *Didaktick* in European-Scandinavian countries overarching by the recently revisited concept *Bildung* may potentially be an alternative approach to the traditional Anglo-American curriculum theory, as it could provide a connection to the ideas of critical scientific literacy (Vision III) and competency (Deng, 2015; Levinson, 2018; Sjöström et al., 2017; Terhart, 2003).

A national curriculum is a good sample for the intended inquiry because it is a policy document conflating and reflecting "modern" and "tradition." It is an assemblage of intended goals showing subject matter, skills, and values that policymakers expect to be taught in schools (Goodlad, 1984; Oliva, 1997). By it, a nation will guide a reform in response to the request in a specific context from the society; the influence from outside on a reform may derive from the global process through international assessments in recent decades (Addey, Sellar, Steiner-Khamsi, Lingard & Verger, 2017; Sellar & Lingard, 2013). Nevertheless, theories of teaching and learning and traditions in education are embedded deeply within the curriculum, because it should have been a product of compromise between a diverse range of stakeholders (Apple, 1993; Cuban, 1992).

In this research, the current national primary science curricula in Finland and China have been selected as the cases for comparison for two reasons. First, the characteristics of the cases are in alignment with the principle of comparative studies: cases have similar outcomes yet with different systems (Steiner-Khamsi, 2013). Finland and China (Beijing, Shanghai, Jiangsu, Guangdong; B-S-J-G) have performed well in international large scales assessment, although they have different educational traditions (OECD, 2011; OECD, 2016). The two countries have been even considered as reference countries in the West and East respectively (Sellar & Lingard, 2013). It is undeniable that the achievements in PISA by these four regions cannot represent the success of the whole of mainland China. However, the results in PISA indicate more of the inequality of education investments in China than the reasons of the achievements which embedded in the traditions and educational system itself. The success of Chinese students is usually explained by examinations, out-of-school lessons, and tutoring by educators from China (Ma, Jong & Yuan, 2013). By contrast, the Finnish education system is even named as a "fourth way" (Sahlberg, 2015). There are far fewer learning hours and tests in Finnish schools than in the Chinese institutions (in general, not specified in Shanghai), thus making the Finnish students' success appears to be a paradox and quite appealing to researchers (Steiner-Khamsi, 2012; Takayama, 2010). The comparative research may help identify characteristics in these countries as well as the traditions embedded in themselves, which may raise a different perspective on curriculum design. Second, the policy documents from the countries are good samples because they fit well with the content for the inquiry, which may entangle the goals of scientific literacy and 21st-century competencies. Finland (2014) and China (2017) have recently published their national primary science curricula as well as frameworks for cultivating 21st-century competencies. The policies indicate a similar concern and even a movement in terms of the integration of 21st-century competencies with school subjects in both countries, admittedly the justification for the reform may potentially differ between the two countries. Educational contexts in Finland and China will be introduced in detail in Chapter 2.

In this dissertation, it is intended to examine how the national primary science curricula in Finland and China specify the objectives of scientific literacy and have incorporated the concept of 21st-century competencies by using the method of deductive content analysis. Even though the thesis merely investigated and compared the intended science curricula in Finland and China, it responds to larger, international concerns. The rhizomatic development of the two concepts, i.e., scientific literacy and 21st-century competencies, across policy documents suggests a common convergent desire to transform the goals of education in front of the challenges for sustainable development. The convergence entails the importance of finding a path to fulfill the purpose. How to design competency-oriented curriculum based on subject matters has become one of the most challenging and even essential issues discussed worldwide (National Research Council, 2012). The approach to integrating the goals of learning 21st-century competencies with traditional school subjects is seemingly more realistic than the radical approach to altogether abolishing all the school subjects. Science as one of the main subjects in school education could promote the development of 21st-century competencies owing to the tenets of the nature of science. However, how? Restructuring the science curriculum by integrating the aims of 21st-century competencies can be a solution that may broaden the goals of scientific literacy in science education to the goals of learning 21st-century competencies through the learning of subject matters of natural science. Traditional theories of curriculum may shed light on the design.

Moreover, there has not been any research comparing the science curricula of Finland and China. By inquiring into the intended science curricula in Finland and China, the thesis presents an examination of the extent to which the visions of scientific literacy, particularly critical scientific literacy, and the goals of 21st-century competencies have been implemented in the policies. The results may serve as reflective materials for the designs of curricula in various countries, as Autio (2014) has argued that the mismatch between advancing theory and education policies is deepening. Although the teaching and learning practices that happen in the classroom are more determinative in the actualization of an educational reform, a few studies have suggested the results of an educational reform may be impacted by the explicit and clarity of the message conveyed in a national curriculum (Bergqvist & Bergqvist, 2017; Cuban, 2013; Fullan, 2001). Consequently, the thesis positions itself in the global challenge – how to design science curriculum with the ideas of developing 21st century competencies – and looks for solutions through the approaches of the comparative study on two reference countries (Finland and China) and of revisiting curriculum theories (*Bildung-Didaktick* and Anglo-American curriculum) with different rationales.

The thesis can contribute to the research fields of science education, curriculum studies, and comparative studies as well. The examinations of policies, particularly research on national curriculum, have not been a major field in science education (Fensham, 2009; Lin, Lin, Potvin & Tsai, 2019), although researchers in science education have noted the ideological issues that are entangled with globalization (e.g., Bazzul, 2012; Bazzul & Carter, 2017; Chiu & Duit, 2011; Kaya, Erduran, Birdthistle & McCormack, 2018; Levinson, 2018). Moreover, the discussion referring to the theories of curriculum based on the findings can contribute to the field of curriculum studies and comparative studies as well. Namely, in the field of curriculum studies, Deng (2018) noted that most of the research has been drawn from such radical broad perspectives that curriculum theorizing is much like cultural studies, and it is therefore argued that it has a "crisis in curriculum theory" by Wraga and Hlebowitsh (Wahlström, 2018) and Young (2013). Topics in areas such as subject matters of curriculum content are not at the center of contemporary curriculum theorizing, although research with broader perspectives on curriculum is undeniably significant for understanding and reflection of curriculum in the increasingly instrumental contexts (Deng, 2018; Young, 2013). Generally, the thesis is a comparative education research and policy study, which can contribute for the theories and discussions on the global governance, specifically promote the understanding of policy borrowing and lending, convergence and divergence, as well as implementation and adoption of the policies from the other nations (Bray, Adamson & Mason, 2007).

The dissertation is comprised of three articles. The overview begins by elaborating the educational backgrounds in Finland and China (Chapter 2). After that, the theoretical backgrounds of the research are described: a review of the two theories of curriculum originally from western countries, and discussion on the goals of scientific literacy and 21^{st}-century competencies (Chapter 3). Then the research questions and methods, as well as the analytical frameworks, are illustrated (Chapter 4). Thereafter, the results of the original articles are briefly presented (Chapter 5). Finally, the thesis concludes with a summary of the findings, a discussion and a reflection of the main points (Chapter 6).

2. Contexts of education in Finland and China

Historically, Finland followed the spirit of *Bildung* inherited from German philosophy, justified and localized by Johan Vilhelm Snellman (Autio, 2014; Saari, Salmela & Vilkkilä, 2014). The Finnish educational system has learned from many countries, including Sweden, Germany, and the UK. After the Second World War, American educational psychology was introduced into Finland and was gradually integrated into the Finnish context (Saari, Salmela & Vilkkilä, 2014). After the Cold War, the logic behind the school system in Finland changed to a capitalist market model with an emphasis on economic and global competitiveness, reflected in educational policy-making and curriculum planning (Saari, Salmela and Vilkkilä, 2014). Nevertheless, Finnish education has still been regarded as a "fourth way" compared with other countries producing high levels of student achievement in international assessments with a relatively small number of teaching hours and average use of resources. Given international and national educational reforms since 1921, the Finnish curriculum is now a mix of the traditional Anglo-American curriculum and the *Bildung-Didaktik* (Autio, 2014; Saari, Salmela & Vilkkilä, 2014).

In the 1970s, Finland made its commitment to a vision of the knowledge-based society. By that time, promoting educational equality has been one of the long-term goals in Finland (Ahtee, Lavonen & Pehkonen, 2008). The idea of introducing a common comprehensive school and university-level teacher education was initiated. The educational system in Finland has been decentralized along with the first national curriculum that was published in 1985, led by the Finnish National Agency for Education (Lähdemäki, 2019). After that, Finland revised its national curriculum every ten years, with updated curricula being published in 1994, 2004 and 2014. The aim of the national curriculum in 1994 was to stimulate a dynamic process in schools. As a result, the decentralization of the educational system was strengthened compared with the one in 1985. However, with the concern about equality between students, the national curriculum in 2004 moved away from decentralization to centralization. However, the national curriculum in 2014 seemingly returns authority to the municipalities and schools when compared with the one in 2004, as the result of educational policy changing with the needs of society. Regardless of the fluctuation of the extent of centralization, most decision-making concerning the organization and even the content of general education was transferred from the national level to the municipalities and even to individual schools in 1985 (Niemi, Toom, & Kallioniemi, 2016; Sivesind, Afsar, & Bachmann, 2016).

The Finnish National Agency for Education prepared the current national curriculum in Finland, the Finnish National Core Curriculum for Basic Education

2014 (Finnish National Board of Education, 2016). The office is a development agency operating under the Ministry of Education and Culture. The designers' concern was that the impact of globalization and the requirement of sustainability in society might reshape the way of providing schooling (Lähdemäki, 2019). The renewing of the national curriculum started in 2012, and a range of stakeholders participated in the development of the curriculum. The stakeholders include the Ministry of Education and Culture, textbook publishers, teacher education organizations, principals, teachers, and other education providers (e.g., municipal education managers). They cooperate and can be separated into steering groups, working groups, and coordinating groups according to their tasks. The design of the curriculum takes two and a half years, and hundreds of professionals have participated in the process. The curriculum was published in Finnish in 2014, and based on the curriculum, local municipalities and individual schools began to develop local curricula, which were ready and became active in August 2016.

In the most recent published national curriculum, Finland proposed seven areas of "transversal competencies": 1) thinking and learning to learn, 2) cultural competence, interaction, and self-expression, 3) taking care of oneself, managing daily life, 4) multi-literacy, 5) competence in information and communication technology, 6) working-life competence and entrepreneurship, and 7) participation, involvement and building a sustainable future (Finnish National Board of Education, 2016). "Multi-literacy" is the competence to interpret, produce, and make value judgments across a variety of texts which will help the students to understand diverse modes of cultural communication and to build their identity. These competencies are highlighted and integrated into the new core curriculum (2014). The seven areas of transversal competencies in the Finnish National Core Curriculum for Basic Education 2014 were required to be integrated into every level of education and every subject (Finnish National Board of Education, 2016; Vahtivuori-Hänninen et al., 2014). Yet, the connotation of how to achieve the competencies, such as multi-literacy, is still in the process of development, although new forms of pedagogy such as phenomena-based teaching have been underlined. The reform trend with explicit highlighting of these competencies in the national curriculum indicates the concerns from Finland on preparing citizens for the fast-changing world.

As the Finnish educational system emphasizes the development of the whole person, all school subjects are seen as equally important (Sahlberg, 2015). Science is taught in Finland from Grade 1. Environmental studies is the name of the science subject at primary school and is taught as an integrated subject by the class teacher. The subject is taught as one compulsory subject in two lessons a week (45 minutes per lesson) in Grades 1-2 (ages 7-8) and on average in 2.5 lessons a week in Grades 3-6 (ages 9-13). The class teachers have been awarded at least a master's degree.

Chinese education is more centralized than Finland's, although efforts were made to modify this in educational reforms in the past few decades (Law, 2014). The Chinese Ministry of Education has the highest authority for planning and designing the national curriculum. Teachers typically follow the objectives in the national curriculum and use their recommended materials. Therefore, the curriculum and its well-organized objectives direct the teaching practices in schools to a great extent. On the one hand, this kind of system limits the teachers' autonomy in teaching, but on the other hand, the system helps to facilitate teachers in clarifying their objectives in teaching, which is particularly essential for the teachers who are inexperienced in teaching or teaching the subject. Data suggests that the percentage of science teachers at primary schools who held master's or higher degrees is less than 10% (Ministry of Education, 2017). It is a much lower percentage than that in Finland, where all primary teachers (100%) have at least a master's degree.

In June 2016, China published the latest version of its document *Core Competencies for Student Development* after four years of research and discussion among researchers, educators, policymakers, and teachers. The essence of the document is to cultivate the individual as a whole by emphasizing core competencies in the following areas: 1) learning to learn, 2) living in a healthy way, 3) taking responsibility as a citizen, 4) practice in creativity and innovation, 5) knowledge of one's cultural heritage, and 6) scientific literacy. The publication plays a role as an additional and umbrella document to guide reforms in China.

Quality and equity are the two significant challenges of basic education in China. The goals of learning the core competencies would not be a new movement in educational reforms in China underneath the umbrella goal called "quality education" (suzhi jiaoyu 素质教育), even if they were released only recently. The ultimate goal of "quality education" is to help students achieve broad and balanced moral, intellectual, physical and aesthetic development and a high level of character building, which is in line with the goal of core competencies. The concept of quality education was proposed in response to the heavy burden of homework and student assessment. However, policies are published to guide the reforms in student-centered and competency-oriented education, but the reality is that it is not easy to change, particularly with the pressure from "Gaokao" (the College Entrance Examination 高考). The national examination has been considered to be one of the biggest events to have an impact on the happiness of life and even as much as the only chance for the socio-mobility of students, particularly students from lower socioeconomic families. The national examination serves as a burden on the goal of quality education, yet it exists as an approach to guarantee the equality of education to some extent.

As a consequence, since the 1990s, Chinese education reforms have highlighted the importance of student-centered learning, but the teaching and learning style has not been changed much. Even if the reality has not been changed much by the series of reforms, the efforts to release students from the burden of examinations have never stopped; specifically the reforms are aimed towards quality education.

Similar to Finland, the Chinese national curriculum is revised about every ten years. “Inquiry” has been highlighted to changing the previous focuses on scientific knowledge and marks in the examinations in science education. The previous Chinese national curriculum (an experimental version) was published in 2001 and revised in 2011 with an emphasis on scientific literacy. The National Primary Science Curriculum in China is an independent document parallel to curriculum documents for other subjects. However, science education at primary schools in China has not been considered to be as important as other subjects, i.e., mother tongue and mathematics. It is because, previously, science was a marginal subject taught from Grade 3 to 6, and the assessment of it would not account in the entrance evaluation of students to junior high schools. Yet, it is changing with acknowledgment of the importance of science education at primary schools by government and schools, perhaps affected by the influence of the science, technology, engineering, arts and mathematics (STEAM) education in the US. Science education at the primary level has been emphasized in recent years. Beginning in autumn 2018, science has been a compulsory subject from Grades 1 to 6 (average ages 6-12, two lessons per week, 45 minutes per lesson), parallel to the implementation of the new National Primary Science Curriculum. Policies have been published on improving the quality of science education and science teacher education. Science is taught by specific subject teachers rather than class teachers in China.

It has generally been argued that curriculum theory in China is a unique combination of Western theories. Contemporary Chinese curriculum studies have taken cues from the US, the Soviet Union, and other countries, such as Japan (Zhang & Gao, 2014). Moreover, historically it is undeniable that Chinese education has been influenced by the idea of Dewey, because his visits to China in the 1920s, and his Chinese students (e.g., Xingzhi Tao) have had significant influence on education with experimental practices. However, their influences on education in China are complex and appear not to be dominant in teaching practices. Education is regarded as the path to improving political or economic status in China (social mobility), especially in the eyes of Chinese parents. This notion highlights the assessment and performance (outcomes) in education, by which students will gain the reputation they want or their parents’ desire. The emphasis on high-stakes testing indicates a contradiction to the original idea by Confucius, which stresses the importance of whole-person development, moral development, through education. Since the 1990s, according to Ding (2015), the Chinese science curriculum has been significantly affected by the traditional Anglo-American curriculum theory. Before 1989 there was no systematic work on curriculum theory, and only in the most recent decades have scholars begun to trace traditions representing ancient Chinese wisdom, such as Confucianism, Taoism, and Buddhism, in order to develop a uniquely Chinese curriculum theory (Zhang & Gao, 2014). Because the influence of traditional wisdom on curriculum theory development in China can be vague and is also new and complex, this aspect of the Chinese science curriculum will not be discussed in the following sections. It will also simplify comparisons with Finland.

3. Theoretical background

3.1 Bildung-Didaktik and traditional *Anglo-American* curriculum

The European-Scandinavian *Bildung-Didaktik* and the traditional Anglo-American curriculum are two major theories of curriculum and practices embedded in western countries (Autio, 2014; Westbury, 2000). American curriculum theory today and *Didaktik* are not far apart from the perspective of the present, because they are similarly concerned with issues of teaching and learning goals. They have also developed dynamically through increasing interaction and globalized influences. Nevertheless, *Bildung-Didaktik* still demonstrates a distinctive perspective in curriculum designing. The relationship among teachers, students and subject matter, as well as the understanding of teaching in classrooms, therefore differ from the traditional Anglo-American curriculum teachers (Pantić & Wubbels, 2012; Westbury, 2000). Generally, the research does not aim to dichotomize the two traditions, but *Bildung-Didaktik* and the Anglo-American curriculum theory refer to a traditional perspective, and the arguments are built on their differences.

The *Bildung-Didaktik* tradition is aimed at cultivating individuals to be competent to live successfully and participate in society and ideally, to reconstruct society (Autio, 2014). *Bildung* is an umbrella concept which has been argued as being different from "education" (Klafki, 2000). As Klafki (2000) noted, "*Bildung* is understood as a qualification for reasonable self-determination, which presupposes and includes emancipation from determination by others. It is a qualification for autonomy, for freedom for individual thought, and for individual moral decisions" (p.87). There are different schools in the understanding and interpretation of *Bildung*. According to classical theory, *Bildung* is understood as general *Bildung*, which includes four dimensions: moral, cognitive, aesthetic, and practical (Klafki, 2000; Autio, 2014). The cognitive, aesthetic, and practical dimensions are considered to be *verstand*, the domain of instrumental rationality. Only the moral dimension differentiates *Bildung* with a reflective mode of rationality from the limits of instrumental rationality, guided by which education becomes educative and at best shifts teaching from the transmission to transformation (Klafki, 2000; Autio, 2014). *Bildung* with all these four domains highlights the importance of individual and social transformation through education, which provides a vision of what education should be.

European-Scandinavian *Didaktik* is a curriculum tradition guided by the *Bildung* concept that highlights the discourse or conversations between the teacher and students about the subject matter in each lesson and shows respect for teachers' academic freedom and autonomy, which is directed by a teaching and learning "triangle" (Autio, 2014; Hopmann, 2007; Saari, Salmela & Vilkkilä, 2014;

Sahlberg, 2015; Westbury, 2000). Thus, although there is a *Lehrplan* (literally, a teaching plan) in the *Bildung-Didaktik* tradition, such a plan could only be meaningful and with educational insights when implemented by well-trained teachers (Autio, 2014; Hopmann, 2007; Pantić & Wubbels, 2012; Westbury, 2000). Nevertheless, the structure of the order of teaching (*Lehrplan*) is necessary for the start of any form of *Didaktik* (Weniger, 2000). The *Lehrplan* is the content of *Bildung*, which establishes the goals of *Bildung* and stipulates the selected instructional material or the so-called "assets" or "values" of *Bildung* (Weniger, 2000). Teachers are considered to be professional experts with freedom within the framework of an illustrated *Lehrplan* and are not assessed solely on the basis of students' learning outcomes (Westbury, 2000).

By contrast, the development of the traditional Anglo-American curriculum has been based on Tyler's Rationale and theories of psychology, which involve standardization and accountability in the educational system. Educational practices developed from this tradition focus on "transmission of knowledge" from society to learners, rather than on educating the whole person (Pantić & Wubbels, 2012; Westbury, 2000). The curriculum and the teaching plans are well-articulated in this tradition, and the educational goals in schools are meant to achieve the stated objectives and the illustrated contents. The teachers are considered to be agents of the system: they can be trained and certified, and they are assessed by the students' learning outcomes (Autio, 2014; Westbury, 2000). Their fundamental responsibilities are to follow and implement the requirements of the national curriculum. One of the strengths of this tradition is its clear objectives in subject matters. Typically guiding by the objectives, teachers can figure out the expected outcomes, which would be more acceptable for the regions where they do not have enough experienced teachers. Another strength of this tradition is it typically concerns the structured learning in subjects, for example, the movement in science education in the 1960s and 1970s guiding in the US, when the US felt that the perceived preeminence in science and its national safety were threatened. The National Science Foundation (NSF) at that time supported science curriculum reforms along with scientists and educators, and developed standards of science education with clear structures and objectives.

Researchers from the US, such as Schwab with the concept of "practical" series and Dewey, share similar ideas in education with the *Bildung-Didaktik* (Deng, 2015; Hopmann, 2009; Ruzgar, 2018). For example, Deng (2018) reviewed Schwab's idea "practical" and build a connection between his ideas with the *Bildung* tradition. Specifically, Schwab's "practical" series is informed by a vision of liberal education centered on an image of an educated person who possesses an understanding of culture and the world and a set of powers that enable him or her to face the challenges in the society of his times. The cultivation of that set of powers is achieved through interactions with the essence of curriculum content, enabled by a liberal curriculum that promotes conversations, discourses, and practical inquiry through a learning community. Likewise, *Bildung*-centered *Didaktik* is directed to a vision of education in terms of *Bildung* – referring to self-formation, encompassing the cultivation of human powers, self-awareness, liberty and freedom, responsibility and dignity, self-determination, co-determination and solidarity (Klafki, 2000). The formation and cultivation are achieved through encounters with the "educational substance" of content embodied in the state curriculum framework, necessitated by the teacher who unlocks the educational potential of content for *Bildung*. However, the ideas of Schwab or Dewey are not discussed in the research. Generally, the theories, as well as other discussions from the field of curriculum studies, indicate the interweaving among subject matters and competencies, and the concerns of the development of a whole person (Wahlström, 2018).

3.2 Scientific literacy and twenty-first century competencies

3.2.1 Three visions of scientific literacy

The term "scientific literacy" has been used to describe diverse goals in science education, although there has been no absolute agreement on the understanding of the concept (Bybee, 2015; Roberts & Bybee, 2014). The definition and scope of scientific literacy have been developed since the appearance of this concept in the 1950s. DeBoer (2000) argued that the emphasis in scientific literacy should be on enhancing the public's understanding and application of science instead of on narrow aims within science itself. Norris and Phillips (2003) analyzed and grouped scientific literacy into fundamental and derived senses of literacy. In contrast to DeBoer's open-ended definition, Norris and Phillips argued for the importance of a fundamental sense of literacy in science education (DeBoer, 2000; Norris & Phillips, 2003; Osborne, 2007). Roberts (2007) summarized two different approaches to curriculum design: In his Vision I, scientific literacy is seen as being knowledge about science; this vision is science-oriented and focuses on teaching the canonic subjects of natural science. Vision II is literacy about science-related situations. It is centered on the public understanding of science and emphasizes the application of knowledge and abilities in various learning contexts. Vision II is the foundation for the view that a science curriculum should be designed to prepare students to be citizens who understand science and scientific literacy. For example, the Science, Technology, and Society (STS) approach is a model based on Vision II (Millar, 2006). Consequently, there appeared to be two conflicting perspectives on designing a science curriculum: focusing on the science subject matters itself or applying knowledge and abilities in real-life contexts. It has been argued that internationally, the science curriculum has been reforming between Vision I and Vision II. Usually, a modern science curriculum is an integration of the two visions (Roberts & Bybee, 2014).

Coincidentally with the changing to Vision II in science education, Gibbons (2000) noted that a Mode 2 with a broader view of understanding the role of science comparing with Mode 1. Mode 2 concerns the system of knowledge production and is more open, which is affected not only by the experts in the field, but also by the personnel from other fields. Gibbons' idea offers a background from the whole society for the essentialness of reform in science education to Vision II.

However, given Gibbons' argument with critical views, it is not difficult to notice the fact that science as a production of knowledge should not have been "pure," which is output by the compromising of various powers. This aspect is also the reason why researchers in science education underline critical scientific literacy. Hodson (2011) stipulated four components of scientific literacy: learning science, learning about science, doing science and engaging in socio-political action. This last component suggests the need for "critical scientific literacy," a need also argued by Levinson (2010, p. 69) as "science education as praxis," and "science education for conflict and dissent" – in effect, a Vision III. Critical scientific literacy is a concern about neoliberalism's influences on science and science education. According to Hodson (2011), "[students] need to be critical consumers of science. This entails recognizing that scientific text is a cultural artifact, and so may carry implicit messages relating to interests, values, power, class, gender, ethnicity, and sexual orientation" (p. 18). Particularly, students are living in an age of social media and fake news emerging from everywhere, which requires them to be citizens with critical view. It should not be enough that students merely acquire the knowledge of science. The background information, such as values, may not be presented in fake news, students, therefore, should develop the competency to notice that. UNESCO has also stressed the need in the *Education for Sustainable Development Goals*: "Education, therefore, is crucial for the achievement of sustainable development. However, not all kinds of education support sustainable development. Education that promotes economic growth alone may well also lead to an increase in unsustainable consumption patterns. The now well-established approach of Education for Sustainable Development (ESD) empowers learners to make informed decisions and responsible actions for environmental integrity, economic viability and just society for present and future generations" (UNESCO, 2017, p. 7).

Thus, Vision III is significant. Vision III implies social-political engagement for value-driven transformations of both individuals and societies focused on emancipation (Sjöström et al. 2017). A Vision III proposed by Sjöström et al. (2017) refers to the *Bildung* tradition. They state that their paper is "[b]ased on critical-hermeneutic *Bildung*… theoretically develops views of critical-reflexive *Bildung* as an educational metatheory. It is connected to ideas of transformative learning, sustainability education, and a Vision III of scientific literacy" (Sjöström et al., 2017, p. 165). Moreover, they cite Dos Santos, who stated, "beyond the purpose of humanistic science education to prepare citizens for the technological society (Vision II), [Vision III] is necessary to have a clearer view of science education as having socio-political function" (Sjöström et al., 2017, p. 182). Vision III demonstrates the concern of connecting science and social science in science education.

Although there is a lack of fixed meanings or definitions of scientific literacy, the PISA science framework sheds light on providing a unique and operational perspective by focusing on the application of scientific knowledge in life situations (Bybee & McCrae, 2011; Fensham, 2009; Sadler & Zeidler, 2009). In PISA, "[Scientific literacy is] the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen. A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology, which requires the competencies to explain phenomena scientifically, evaluate and design scientific inquiry, and interpret data and evidence scientifically" (OECD, 2013, p. 7). It is difficult to tell if scientific literacy in PISA explicitly indicates perspectives of Vision III, yet it indeed clearly demonstrates a concern of the Vision III with the goal of "reflective citizen." The PISA science framework shows an emphasis on Vision II, as Sadler and Zeidler (2009) have argued that the PISA framework with its focus on scientific literacy aligns well with socio-scientific issues, even if the test items do not fulfill the intent of the socio-scientific issues. Nevertheless, Roberts & Bybee (2014) noted that the framework of PISA 2013 has a tendency moving to Vision I comparing that in PISA 2006.

To sum up, these three visions of scientific literacy have different emphases in a curriculum: Vision I (the conceptual approach) highlights scientific knowledge and the structures of science, including content knowledge and procedural knowledge. Vision II (the contextual approach) emphasizes utility and the meaningfulness of STEAM in life. The most crucial characteristic of the Vision II is its goals of contextualizing science teaching and learning. Vision III (the critical approach) stresses teaching and learning science as a means of achieving both individual and societal transformation; specifically, it shows a tendency to encourage political action or participation in socio-scientific issues contexts. Vision III is based on a concern of transformation of the individual and society. The vision extends the previous boundary of science education, which limits itself in science rather than connects with and reflects on society. The curriculum design based on Vision III is challenging, but it has been argued that it is possible through a purposeful design that can even be suitable for primary school students (Levinson, 2018).

3.2.2 Goals of learning twenty-first century competencies

As discussed previously in the Introduction section, the concept of 21st-century competencies has been shown in various educational policies around the world. Its appearance seems to be in line with the concern about the future job market or the rationale of the capital market. In order to survive in the future society, students should equip themselves with core competencies that can be transferred into different areas and adaptable to different jobs. Many supranational organizations, such as the OECD and the EU, were some of the first organizations to publish documents outlining educational goals for the 21st century using specific frameworks. Meanwhile, international companies such as the Intel Corporation and Microsoft have collaborated with educators and educational institutions to develop frameworks for teaching or assessing 21st-century competencies (e.g., Assessment and Teaching of 21st Century Skills, ATC21S). Following these institutions, countries around the world have proposed their frameworks for 21st-century competencies (e.g., China, Finland, Singapore, and the US). However, there is neither agreement on the terminology with which to crystallize the idea of the goals of these competencies, nor an absolute consensus of what competencies belong to the umbrella concept. On the one hand, the complexity is influenced by cultural differences. On the other hand, supranational and national institutions may have been “copied” or “borrowed” from each other, because the organizations have used different terms in an attempt to distinguish between individual documents from documents published by others. In general, it has been agreed that competency is an integration of knowledge, skills, attitudes, and values which are required for citizens to participate fully in society in the 21st century (Ananiadou & Claro, 2009; European Union, 2008; National Research Council, 2012; Voogt & Roblin, 2012).

Policymakers at different institutions are in favor of initiating terms and frameworks on these competencies to direct the way for development. Meanwhile, researchers and educators have been discussing how to achieve the goals of teaching and learning these competencies, regardless of the different terms that have been applied. Typically, there are two practical approaches. One is to operate an independent teaching unit, and the other is to abolish the traditional school subjects altogether. Researchers such as Willbergh (2015) held critical views on the second approach, in that the concept does not build on educational theory, it only projects anxiety from society to education, with an attempt to use education as a tool to solve its problems. Moreover, researchers have reclaimed the importance of acquiring knowledge in a systematic way. For example, Young (2013) proposed the idea of powerful knowledge, in response to his concerns about the diminishing positions of subject matter along with increasingly favoring “competency” in education.

In order to solve the problem, it is considered that *Bildung*, one of the educational umbrella concepts, provides an educational theory for the goals of achieving “competencies.” According to the critical views, they suggest teaching the competencies via the teaching of traditional school subjects is an alternative strategy with high potential. To put it differently, it is more practical by the method of broadening previous goals of learning in subjects to learning by subjects.

Science is one of these subjects which can provide content to cultivate competencies (Deng, 2015); these competencies can be specified in science and may also be transferred to other areas that play an essential role in rational life in the future. For example, empirical research in science education has been undertaken to examine whether students' skills in inquiry and critical thinking can be improved by learning science and how to improve these competencies by purposeful design of science teaching (e.g., Crawford, 2007). In recent decades, the volume of research on "argumentation" in the literature indicates an emerging awareness of developing competency of communication and critical thinking in and beyond science (Osborne, 2014).

In summary, science curriculum may be re-theorized with the subject matter of science and guided by the goals of acquiring 21st-century competencies. Learning from curriculum traditions, such as curriculum design guided by *Bildung* culture, could be a possible way. Meanwhile, the objectives of content in disciplines such as science can still be systemically organized.

4. Aims and methods

4.1 Aims of the research

The object of this research is to examine whether and how the Finnish and Chinese national primary science curricula have specified and adopted the concepts of scientific literacy and 21st-century competencies. The research attempts to identify how the two curricula nationally re-contextualized the two concepts and provide interpretations of the findings referring to the theories of curriculum. In return, the findings will shed light on the improvement and integration of the analytical frameworks, which will serve as a fundamental to restructuring science curriculum with the understanding of theories of curriculum.

The dissertation is a collection of three original publications summarized in Table 1. The general and specific research questions of each study are as follows:

1. How have the current Finnish and Chinese national primary science curricula specified the scientific literacy-related objectives? (Study I)
   a) How are the objectives of scientific literacy in the two curricula in alignment with the categories in the revised PISA framework?
   b) What are the similarities and differences in the emphasis on the various categories of the PISA framework between the two curricula?
   c) How can the similarities and differences be interpreted in terms of the three visions for scientific literacy-oriented curriculum design and the two theories of curriculum?

2. What are the connotation and components of 21st-century competencies? Has the current Chinese national primary science curriculum adopted the concept? (Study II)
   a) How have the selected organizations conceptualized 21st-century competencies? What are the agreements and distinguishing features of 21st-century competencies in the selected documents?
   b) Can the objectives of 21st-century competencies be identified in the current Chinese science curriculum?

3. How have the current Finnish and Chinese national primary science curricula adopted the concept of 21st-century competencies? (Study III)
   a) How are 21st-century competencies described in the two curricula?
   b) What are the similarities and differences in the emphasis on the set of 21st-century competencies between the two curricula?
   c) How can the similarities and differences be interpreted in terms of the theories of curriculum?

Table 1. Overview of the studies

Study	Objective	Analytical framework	Material	Method
Study I	To conceptualize scientific literacy and formulate an analytical framework for it To examine to what extent and how the two curricula have specified the objectives of scientific literacy	The revised version of the PISA science framework	- Environmental studies in Finnish National Core Curriculum (Grade 1-6) 2014 (referred to as the Finnish curriculum) - Chinese National Primary Science Curriculum (Grade 1-6) 2016 (referred to as the Chinese curriculum)	Content analysis was used to identify and compare the similarities and differences in the two curricula.
Study II	To conceptualize 21st-century competencies and formulate an analytical framework for it	Framework with six categories: intention, target group, terminology and connotation, the basis for categorization, general competencies, and competencies linked with traditional school subjects	- Learning: the treasure within (UNESCO), - Toward Universal Learning: What Every Child Should Learn (UNESCO), - The Definition and Selection of Key Competencies (OECD), - The Program for International Student Assessment Frameworks (OECD), - ATC21S (an international project group), - Key Competencies for Lifelong Learning (EU), - National Core Curriculum for Basic Education 2014 (Finland), - Core Competencies for Student Development Proposal (China)	Content analysis was used to identify the agreements and differences in the descriptions of 21st-century competencies in the selected documents.
	To test the framework, correspondingly, to examine whether 21st-century competencies in science curriculum has adopted the 21st-century competencies concept	ATC21S (Assessment and Teaching of 21st-century skills) (The framework focuses on generic competencies.)	Chinese National Primary Science Curriculum (Grade 1-6) 2016 (referred to as the Chinese curriculum)	Content analysis was used to identify if the goals of 21st-century competencies have been integrated into the Chinese science curriculum. The method also serves an examination of the ATC21S based on the findings.

Study	Objective	Analytical framework	Material	Method
Study III	To revise the analytical framework of 21st-century competencies with a science emphasis; to examine whether and how the two curricula have adopted the concept of 21st-century competencies	An analytical framework based on the revision of ATC21S (The framework integrates a concern on the objectives of learning science.)	- Environmental studies in Finnish National Core Curriculum (Grade 1-6) 2014 (referred to as the Finnish curriculum) - Chinese National Primary Science Curriculum (Grade 1-6) 2016 (referred to as the Chinese curriculum)	Content analysis was used to identify and compare the similarities and differences of the objectives of the 21st-century competencies in the two documents.

4.2 Methods

As mentioned above, the aim of this research is to a) examine the implementation of concepts of scientific literacy and the adoption of the concept of 21st-century competencies in the contexts of Finland and China, b) to build up and reflect on conceptual frameworks of scientific literacy and 21st-century competencies. All three papers applied content analysis to examine the material, because a) the method can retest existing data in a new context with structured theories or models or compare categories, b) the approach can help extend a theoretical framework or theory conceptually (Elo & Kyngäs, 2008; Hsieh & Shannon, 2005).

The studies followed the principle and procedures of deductive content analysis, which basically includes five main steps: 1) developing the analytical frameworks based on theories (literature) (i.e., defining the main categories and subcategories); 2) making coding agendas (i.e., explicit definitions of the codes, examples and coding rules); 3) a pilot testing and formative check of reliability; 4) revising categories and coding agenda; 5) working through of the texts, the summative check of reliability, and calculating the frequencies and percentages in categories (Elo & Kyngäs, 2008; Mayring, 2015; Schwarz, 2015; Weber, 1990).

Regarding the thesis, the three studies were analyzed within different frameworks for the distinct objectives respectively as summarized in Table 1. The descriptions of the frameworks are presented in the next section. A set of pilot tests was conducted through parts of the documents by two of the three coders and thereafter the codes were further clarified according to the discussion of the three coders. The three coders are my two supervisors, and me. The Analytical Framework section illustrates the coding process with examples to show how each unit was identified and situated into a specific code. After finalizing the analysis frameworks, the whole texts were analyzed. Then, each study calculated the observed frequencies of the units in each code (and category). Finally, a chi-square test (χ^2) was carried out in Study I and Study III to compare the similarities and differences between the Finnish and Chinese national primary science curricula regarding scientific literacy and 21st-century competencies respectively. Coding agreements were checked throughout the research. The validity and reliability of the analysis are discussed at the end of the chapter.

4.3 Analytical Framework

The first study reports on how scientific literacy as the main goal of science education has been emphasized in science curricula. Therefore, the framework applied in Study I was based on the scientific literacy literatures. The PISA science framework (OECD, 2013) was used as a working framework for pilot analysis because the PISA science framework was based on the idea of assessing scientific literacy. Then, the analysis framework was revised based on the PISA science framework into the one shown in Table 2, after the pilot analysis spotted ambiguous definitions and overlooked codes in the PISA science framework. For example, “Apply scientific knowledge in practice (Practices)” was added in the revised framework, because the study is particularly for younger age students, who may learn science closely related to their daily life through hands-on practices (Roth, 2014). “Ethics in Science” is another example. This code was added because it was not explicitly pointed out in the PISA science framework, yet it is a significant aspect of science education particularly with the view of Vision III and sustainable development. The code concerns the dependent role of science in society, the social aspects of the nature of science, and the importance of how facts and values interact (Hodson, 2011; Kaya et al., 2018; Levison, 2010). Appendix 1 illustrates all the codes and their working definitions.

Table 2. Analysis framework of Scientific Literacy (Study I)

Category	1 Scientific Competencies	2 Scientific knowledge	3 Attitudes to science	4 Learning Contexts
Code	1) Explain phenomena scientifically 2) Evaluate and design scientific inquiry 3) Interpret data and evidence scientifically 4) Apply scientific knowledge in practice	1) Content knowledge a) Physical systems b) Living systems c) Earth and space systems d) Technology and engineering systems 2) Procedural knowledge 3) Epistemic knowledge	1) Interest in science 2) Self-efficacy and self-concept 3) Disposition of scientific approaches to inquiry 4) Environmental awareness 5) Ethics in science	1) Topics a) Health and disease b) Natural resources and technology c) Environmental quality d) Hazards e) Frontiers of science and technology 2) Perspectives a) Personal b) Local c) Global

Study II was conducted with two matrixes. The first matrix includes six categories: intention, target group, terminology, and connotation, the basis for categorization, general competencies, and competencies linked with traditional school subjects. The matrix was used to examine how the 21st-century competencies have been discussed in various policy documents. The policy documents were selected in line with the comparative view noted by Bray and Thomas (2007), which include policies at supranational and national levels deriving from various cultural backgrounds. The analysis process with the matrix merely followed the principle of content analysis to analyze data qualitatively rather than quantitatively calculating the data. Based on the qualitative analysis findings, the *Assessment and Teaching of 21st Century Skills* (ATC21S) was chosen as the conceptual analysis framework through which to examine the adoption of 21st-century competencies in the Chinese curriculum as well as improve the framework. Table 3 shows the codes of ATC21S (Binkley et al., 2012). The deductive content analysis of the Chinese curriculum was applied for two purposes. First, it was to test whether the Chinese curriculum has adopted the concept, particularly whether the aims of learning generic competencies have been integrated into the Chinese curriculum. Second, it was to prepare a conceptual framework for Study III.

Table 3. Analysis framework of 21st-century competencies (generic competencies focused, Study II)

Category	1 Ways of thinking	2 Ways of working	3 Tools for working	4 Living in the world
Code	1) Creative thinking and generating of innovations 2) Critical thinking, problem-solving, decision making 3) Learning to learn, metacognition	1) Communication 2) Collaboration (teamwork)	1) Information literacy (research on sources, evidence, biases, etc.) 2) ICT literacy	1) Citizenship, personal, local, and global 2) Life and career 3) Personal, social, and global responsibility

The analytical framework used in Study III was a revised framework based on Study II (see Table 4). The framework attempts to distinguish itself from the ATC21S by including new codes and redefining previous codes. The revisions demonstrated concerns about developing 21st-century competencies through the learning of science, or to put it in another way, the revised framework was used to examine 21st-century competencies adoption with an emphasis on science education. Here follow two examples to demonstrate the identical differences of the revised framework from the framework used in Study II. More definitions of the codes and examples are illustrated in Appendix 2. The first example is two of the new codes. “Inquiry” and “Problem-solving” are the codes added into Category 2 “Ways of working,” because these two competencies should be the skills underlined in the field of science education. The competencies are closely connected with essential skills for the twenty-first century. The other example is one of the redefined codes but using the same name “Information literacy.” Information literacy has been seen by research in different ways. According to Association of College & Research Libraries (ACRL), information literacy is defined as a set of abilities that allow individuals to recognize when information is needed and to locate the required information, evaluate it and use it effectively (Blummer & Kenton, 2014). In order to contextualize this definition in science education, the competency refers to the ability to recognize and comprehend scientific concepts, and to locate and use the concepts when needed for a certain context. Therefore, explaining phenomena using scientific concepts should be regarded as one of the competencies belonging to this code.

Table 4. Analysis framework of 21st-century competencies (science-related, Study III)

Category	Category 1 Ways of thinking	Category 2 Ways of working	Category 3 Tools for working	Category 4 Living in the world
Code	1) Critical thinking 2) Creative thinking 3) Using metacognition (Learning to learn)	1) Collaboration 2) Communication 3) Inquiry 4) Problem-solving	1) Information literacy (including understanding science concepts) 2) ICT literacy	1) Citizenship 2) Life and career 3) Personal, social, and global responsibility

4.4 Coding

Coding was based on the coding agenda to identify meaningful sections and therefore to put each identified unit in a code listed in the frameworks appropriately. The coding unit was not confined to word, sentence, or paragraph. Each coding unit includes one idea. Examples are provided to illustrate the coding process, yet these examples do not cover all the codes shown in the previous section (see Table 5). Appendices 1 and 2 illustrated more codes and identifiable words to demonstrate how texts were analyzed.

Table 5. Examples of the coding process

Data analysis (units are underlined)	Code	Description of reasons for the coding in brief
[Teachers should] guide the student to <u>explore</u>, <u>describe</u>, and <u>explain</u> the <u>physical phenomena</u> encountered in <u>daily life</u>, nature and technology… (the Finnish curriculum, p. 7).	- Explain phenomena scientifically - Physics systems - Content knowledge - Personal	First, the verbs demonstrate the requirements for competency, and the competency belongs to explain phenomena. Second, physical phenomena present a supportive knowledge of the competency, which is content knowledge in physical systems. Third, “encountered in daily life” presents the contexts of learning, which belong to a personal environment.
Students can use a <u>lever, pulley, slope, axle, or other simple machines</u> to <u>solve practical problem</u>s in <u>daily life</u> (the Chinese curriculum, p.37).	- Practices - Technology and engineering systems - Problem-solving - Personal	First, the usage of the tools to solve the problem demonstrates two competencies. One is the “practices” in scientific literacy, and the other is “problem-solving” in general. Second, using these tools is based on the knowledge in technology and engineering systems. Third, it was coded into “personal” because the contexts of the learning situate in “daily life,” closely related to personal life.

4.5 Validity and Reliability

Content analysis in the research is considered to be a mixed-method, an integration of quantitative and qualitative modes of analysis, although methodological debates remain owing to alternative inquiry paradigms (Mayring, 2015; Prior, 2014). Different terms, such as validity, trustworthiness, goodness, have been interpreted in many ways by different scholars (Cho & Trent, 2014). Yet, the research does not aim to differentiate the terms from each other, but rather uses the two terms, i.e., validity and reliability, which were originally used in quantitative studies. Techniques have been followed throughout the research to ensure validity (Cho & Trent, 2014; Lincoln & Guba, 1985).

Validity is used to demonstrate that the research can reflect reality. The analytical frameworks, i.e., frameworks of scientific literacy and 21st-century competencies, used in the three studies are well-recognized models worldwide and any revisions of the frameworks were done based on international literature, which has been discussed in previous chapters. The definitions of the codes were based on literature reviews and discussions with experts in the fields. Specifically, all the coding agendas (including definitions of the codes) were pilot tested — discussions on revising them by the three researchers, i.e., the two supervisors and me. One of the supervisors is an expert in science education, and the other has expertise in comparative studies across countries. After a series of pilot tests and revisions of the coding agendas, we agreed on a working version of the coding agenda including coding examples and principles. The defining codes process has been done in an iterative way until we accepted a final version of the analytical frameworks and definitions of codes. These frameworks as the tools for analysis provide a neutral perspective for the comparison of the curricula in different countries.

Reliability shows that the results have reached an acceptable level of consistency. With the coding guidelines, some of the documents were analyzed independently by me and the supervisor with expertise in science education. The formative agreement between us was 0.5. Then the three coders reviewed the differences of the coding and improved the coding guideline further. After the revision, the final agreement between the two coders' independent coding reached 90% by using the final version of the conceptual frameworks. Cohen's kappa exceeded 0.84, and the 0.81—0.89 range represents a perfect agreement, with the number demonstrating the interrater reliability of the studies.

5. Results

5.1 Scientific literacy-related objectives in the Finnish and Chinese science curricula (Study I)

Article I, "An assessment of how scientific literacy-related objectives are actualized in National Primary Science Curricula in China and Finland," examined how Finnish and Chinese national primary science curricula (hereafter referred to as the Finnish curriculum and Chinese curriculum) specified the concept of scientific literacy.

The study first identified the structure and the core goal of science education described in the Finnish and Chinese curricula. As a whole, the structure and basic content of the two curricula are similar. Both curricula cover the objectives of knowledge, competencies, attitudes or values, even if they are provided in different ways. Moreover, the general tasks of science education appear similar in terms of the goal of knowledge and commonly recognized competencies in science, cultivating future citizens with the awareness of environment, and promoting the development of lifelong learning skills and interest in science. Yet, the rationale and emphasis of the goals described in the two curricula are different. The Chinese curriculum suggests the reason for learning science at the primary level is to prepare students to learn higher-level skills. Moreover, the reason to bolster the learning of science at the primary level is that science is crucial for success in the development of society and economics. Namely, "With the development of science and technology, new scientific discoveries and technological creations are emerging every day. Science and technology play an essential role in social and economic development…." (the Chinese curriculum, p. 1). "Scientific literacy" is the key concept declared in the Chinese curriculum; it appears 11 times. By contrast, the Finnish curriculum justified the learning of science (entitled "environmental studies") intending to communicate with the environment, specifically, "[I]n environmental studies, students are considered part of the environment in which they live. Respect for nature and a life of dignity in compliance with human rights are the basic principles in teaching and learning…. Students are supported to build a relationship with the environment, develop their worldview and grow as human beings" (the Finnish curriculum, p. 1). At least, the economic aspect does not been mentioned explicitly in the Finnish curriculum. Besides, "scientific literacy" has never been mentioned in the Finnish curriculum. Alternative concepts were identified, such as "sustainable development" and "health and well-being." However, there were no further explanations of the terms in the Finnish curriculum. The implicit information conveyed by the terms can only be an assumption, such as the rationale inclines with personal development instead of economic development.

Next, the two curricula were examined with the revised PISA framework. Both curricula have units belonging to all four main categories, namely, scientific competencies, scientific knowledge, attitudes to science and learning contexts. Objectives of scientific knowledge constitute the major part of the two curricula. Nevertheless, objectives of scientific competencies have been purposefully mentioned in both curricula when the objectives of knowledge are introduced, and the objectives are situated in contexts. A chi-squared test was carried out to find the differences in the distribution of subcategories between the two curricula. There are significant differences in the distribution of the subcategories in, namely, "scientific competencies," "scientific knowledge," "content knowledge" and "learning contexts" (both topics and perspectives) between the Finnish and Chinese curricula. The Finnish curriculum suggests an emphasis on competencies of "Enquiry" and "Practices" than the Chinese curriculum does. By contrast, the Chinese curriculum shows more emphasis on the competencies of "Explain" than that the Finnish curriculum does. In terms of the scientific knowledge, the Finnish curriculum presents a higher percentage on procedural knowledge than the Chinese curriculum, yet the Chinese curriculum indicates more emphasis on content knowledge than that in the Finnish curriculum. This may be related to the emphasis on "Enquiry" in the Finnish curriculum. Competency of "Interpret" has the lowest percentage in both curricula as well as "epistemic knowledge." It is understandable because competency and knowledge require higher-level cognitive development, which may not be proper for the students at primary school age. In terms of the areas of content knowledge, the results show that the Finnish curriculum placed more emphasis on living systems and physical systems, whereas the Chinese curriculum has a more equal division in these areas than that in the Finnish curriculum, even if "earth and space systems" and "technology and engineering systems" are not emphasized as much as the other two areas in the Chinese curriculum. In terms of the distribution of learning contexts of the topics, both curricula demonstrate the most emphasis on the "environmental quality" topic and the least on "frontiers of science and technology." In terms of the distribution of codes in learning contexts in the perspectives, both curricula demonstrate concerns about the content connected with personal-level experiences. Considering the other two perspectives, the Chinese curriculum emphases more on global than the local perspective, by contrast, the Finnish curriculum shows more emphasis on situating objectives with a local perspective than that with a global perspective.

The quantitative results can merely present some of the findings. Quotations as qualitative data may bring additional information to allow us to understand the differences between the curricula. One of the outstanding examples would come from the category "attitudes to science." Quantitatively, the differences in the distribution of attitudes to science between the two curricula were not significant, $\chi^2(4, N = 179) = 2.1, p = 0.71$. However, quotations from each curriculum indicate different perspectives of writing the intended curriculum and the role of a national curriculum (Examples are shown below as well as in Article I). The Chinese curriculum was written from the perspective of students' learning outcomes. With it the teacher's role and responsibility are not clear, and therefore ironically students are considered to be responsible for the development of attitudes in all the aspects. The Finnish curriculum illustrates the opposite stance. It explicitly shows the teacher's role as a supporter to facilitate the students' development. Teachers' responsibilities are given in principle but clear enough.

Examples:

Interest in science:

> "[S]tudents should remain curious about natural phenomena and remain passionate about the inquiry." (the Chinese curriculum, p. 8).
>
> "[Teachers should] attract and deepen the students' interest in the various fields of environmental studies." (the Finnish curriculum, p. 1).

Self-concept or self-efficacy:

> "[Students should learn to] overcome difficulties during research and complete the scheduled tasks." (the Chinese curriculum, p. 8).
>
> "[Teachers should] recognize students' competence in environmental studies and [support the students to] make persistent efforts to achieve [personal study goals]." (the Finnish curriculum, p. 6).

Disposition of scientific approaches to inquiry:

> "Students should develop an awareness that they must present their ideas based on evidence and proper reasoning." (the Chinese curriculum, p. 8).
>
> "The student should be encouraged to wonder and ask questions…." (the Finnish curriculum, p. 2).

Environmental awareness:

> "[Students should] formulate an awareness to protect the environment and take social responsibility…." (the Chinese curriculum, p. 8).
>
> "[Teachers should] support the development of the students' environmental awareness." (the Finnish curriculum, p. 2).

5.2 Conceptualization of 21st-century competencies and a pilot assessment of the competencies in the Chinese science curriculum (Study II)

Article II, "*Twenty-first century competencies in the Chinese science curriculum*," compared the connotation and set of competencies of the 21st-century competencies concept in eight policy documents at national and supranational levels and examined whether the Chinese curriculum adopts the concept using the revised ATC21S framework.

By comparing the selected policies, the study found a similar rationale for the importance of competencies across the policies. The reason for teaching and learning the competencies is that equipping future citizens with the competencies can fulfill the changing and unpredictable society and labor market. Even if diverse terms have been used to present the goal of fulfilling society demands, the policies demonstrate convergence in the connotation of the "competencies," which is an integration of knowledge, skills, values, and attitudes and can be applied to certain contexts in need. Then the study examined the set of competencies under the umbrella goal "21st-century competencies" in different policies. The results demonstrate similarities in the selection of general or transferable skills, such as communication, creativity, and ICT; as well as some competencies learned in traditional school subjects, for example, mathematics and reading. However, there appears to be a difference between the policies in the selection of competencies owing to different contexts in cultural, political, economic and other contexts. For example, foreign languages are considered to be one of the core competencies.

The study recognized the challenges in actualizing the integration of 21st-century competencies into a curriculum based on traditional school subjects systemically. The research assumes the potential of teaching and learning the generic competencies in 21st-century competencies by the means of learning science. In order to understand the status of the integration of the objectives in science curriculum and to initiate an internationalized standard of 21st-century competencies, the study examined the integration of the objectives of 21st-century competencies in the Chinese curriculum by ATC21S. The study found the competencies belonging to 21st-century competencies have been integrated into the Chinese curriculum, even though they were not integrated systematically. Most of the objectives related to 21st-century competencies have appeared in the sections of preface and general aims declaration. There also appears differences across the competencies in percentages. Critical thinking and creativity are two of the most highlighted generic 21st-century competencies in the Chinese curriculum. The emphasis on these competencies indicates a special consideration from the Chinese government to cultivate talent in science which is in line with the education reforms since the 1990s.

5.3 Whether and how the Finnish and Chinese national primary science curricula adopted the concept of the 21st-century competencies (Study III)

Article III, "*Aims for learning Twenty-first Century Competencies in National Primary Science Curricula in China and Finland*," compared whether and how the 21st-century competencies have been adopted in science curricula in Finland and China with a revised conceptual framework of 21st-century competencies with the emphasis on science.

The quantitative data suggest both curricula have adopted the concept shown as the integration of the objectives belonging to the set of competencies listed in the analysis framework. “Information literacy,” “inquiry,” “citizenship,” and “learning to learn” are the competencies that have been stressed in both curricula. “Information literacy” and “inquiry” are the competencies that apparently depended on science subjects. “Critical thinking” and “creative thinking” are the competencies that are not the most emphasized in either curriculum according to the observed frequencies.

A chi-squared test was applied to examine the differences in the distribution of subcategories between the curricula. In general, the data suggest the differences in the distribution of the 12 competencies between the curricula are statistically significant. Despite the distribution difference of subcategories in the “Ways of Thinking” across the curricula not being statistically significant, the distribution differences in the other three categories are significant. The Chinese curriculum suggests less emphasis on the “Living in the world” category than that in the Finnish curriculum. In particular, there are no objectives in the Chinese curriculum belonging to the code “Life and career.” By contrast, in the Finnish curriculum, the objectives in this code have been declared by presenting the importance of happiness in the changing world. Namely, well-being is one of the keywords. The results found the Finnish curriculum cares about students’ emotional wellness. For example, “… support the student in recognizing, expressing, and regulating his or her emotions” (the Finnish curriculum, p. 6). Yet, neither objective closely related to a career in science has been discussed in the Finnish curriculum. Moreover, the code “personal and global social responsibilities” is almost absent from the Chinese curriculum, and by contrast, it is shown 16 times in the Finnish curriculum. The appearance of this code in the Finnish curriculum indicates a connection of education in social aspects with science education. For example, “Using versatile regional examples and topical news items, the students learn to perceive the natural environment and human activities in Finland, the Nordic countries, Europe, and other continents” (the Finnish curriculum, p. 8).

6. Discussion

6.1 Summary of studies I, II, and III

The first study examined the specification of objectives of scientific literacy in the Finnish and Chinese national primary science curricula. The objectives of scientific literacy for both curricula are based on scientific knowledge (Vision I) and the application of knowledge-based skills in situations (Vision II). It demonstrates an integration of the two visions. Moreover, the Chinese curriculum appears to have a tendency in line with Vision I compared to that in the Finnish curriculum. The objectives situating with contexts in the Finnish curriculum are higher than those in the Chinese curriculum. However, both curricula are characterized by implicit views that derive from the pursuit of the value-driven transformation of individuals and society achieved through science education (Vision III). In general, the Chinese curriculum appears to favor the traditional Anglo-American curriculum, whereas the Finnish curriculum appears to be more attached to the *Bildung-Didaktik* tradition in terms of core tasks and the specification of objectives.

The concept of 21st-century competencies has been delineated according to the second study's analysis of various frameworks of 21st-century competencies. The study also shows that the Chinese national primary science curriculum has adopted the concept. The analytical framework (ATC21S) tested in the study enables comparison with the implementation of the concept in the Finnish and Chinese science curricula. The third study, therefore, compared the Finnish and Chinese national primary science curricula in their adoption of the 21st-century competencies with the revised ATC21S framework. The findings further support the arguments in the first study that the Finnish curriculum suggests an alignment with *Bildung* tradition whereas the Chinese curriculum does not. First, the goals of 21st-century competencies integrated into the Finnish curriculum explicitly demonstrates the concern of the educational aims for the development of a moral and holistic individual. It indicates that science education as a means to the end of the formation of individual and society. By contrast, even if the Chinese curriculum has adopted the concept of 21st-century competencies, the rationale and objectives are still confined to science. Moreover, the Chinese curriculum suggests limited concerns on developing the whole person rather than the focus on the science contexts when compared with the Finnish curriculum.

In addition, the length of the text of the curricula and the perspectives described objectives in the two curricula are different. The Finnish curriculum mostly describes the objectives by themes and as a guideline for teachers; very few objectives were presented from the perspective of students' learning outcomes. In contrast, the Chinese curriculum provides objectives in detail, and most of them are provided in line with content in disciplines. These differences strengthen the argument that the two countries' science curriculum shows different affiliations to the two theories of curriculum, i.e., *Bildung-Didaktik* and Anglo-American curriculum.

6.2 Implications

The examinations of the implementation of the concepts, i.e., scientific literacy and 21st-century competencies in the Finnish and Chinese science curricula have the implications for the understanding of "glocalization" of international standards. First, the findings help to explain the glocalization phenomenon of policy initiation, which illustrates a complex integration of global trends and local contexts at the national level represented through the national curriculum. Second, the findings reinforce the argument that any declared reforms at the national level using worldwide recognized fancy slogans may vary in their meanings. Therefore, any declaration should be examined because the objectives described with abstract concepts may affect the outcomes of their implementation. Consequently, the clarification of "concepts" by developing structured international standards explicitly should be significant, which can guide the educational reforms around the world at a similar pace. But people may refute internationalized standards with the concerns that globally uniform reforms may decrease diversity and increase the inequality in education. However, the worries are not necessary because each country can initiate the policies consistent with its context. Nonetheless, internationalized standards should be helpful in guiding countries in developing their standards and keep pace with the most recent movements globally, which is particularly significant for countries with developing education systems.

Second, the findings indicate the essentialness of drawing reflections on the concepts widely accepted and applied, because some ideologies may implicitly be embedded in the concepts, which may prevent the development of a sustainable society. For example, the examination of the two curricula suggests a limited concern on Vision III of scientific literacy. The result indicates the importance of initiating frameworks as assessment tools with critical views for understanding the implementation of the concepts in countries. The examination of the concepts with the tools would be beneficial for curriculum design and the implementation of a new curriculum in a classroom in various nations. Through the examination, policy-makers and teachers can identify the strengths and weaknesses of their actualized curriculum. This aspect is significant because reflection is particularly critical in education, to know what we have known and what we do not know. In this thesis, two tentative frameworks have been proposed, i.e., the revised PISA framework and the revised ATC21S. These frameworks can be used as a guide for examining curriculum design and practices in different countries. The frameworks can be used for curriculum design for all the levels of basic education, but there should be a continuum of the subject matters and different requirements for particular competencies or knowledge. Additionally, these analytical frameworks can be used for future research in curriculum studies to compare and find potential differences and similarities.

Finally, the findings suggest an opportunity to re-theorize the science curriculum. Science education can be both a goal in itself, and a means for attaining “competencies” for the 21st century. Scientifically-literate citizens are the foundation of the sustainable development of society, such as the importance of environment protection, if science is considered as the end itself. Guiding with the idea that science is a means for the ultimate goals of education, 21st-century competencies can be taught within the science subject as well. Furthermore, science education can be regarded as an approach to fulfilling the transformation of individuals and society, which is aligned with the idea of *Bildung*. Therefore, *Bildung* is an essential concept for designing and implementing a curriculum. Guided by the concept, science education can be considered with broader goals, incorporated reflections on the ideologies and aimed for transformation of the individual and society, because the moral aspect is the leading dimension of *Bildung*. Nevertheless, the traditional Anglo-American curriculum theory plays a vital role in curriculum design as well. Subject matters and well-structured content in subjects are foundations of a well-designed curriculum. This theory would guide the design in the content of the science discipline with well-articulated objectives. According to the theory, curriculum should clearly show the outcomes expected from students. A combination of the two theories is necessary. Thus, the restructured science curriculum not only values the objectives of scientific literacy in science education as an end in itself, but more importantly, it values science education as a means to the end of the goals of 21st-century competencies. The idea is in line with the goals of education for sustainable development outlined by UNESCO.

6.3 Limitations

The research has several limitations, yet it can suggest topics for future studies. First, the research regards each observed unit as being equal and unweighted according to its importance or teaching hours. It means that the quantitative results based on the observed frequencies can merely be used to indicate a tendency to emphasize differences in the various codes across the curricula. The codes may be weighted according to the intended distributions of lessons in future studies.

Second, the research only observed the intended/official curricula in the two countries, meaning that the research may not show the real status of education in each country. The actualized curriculum in the classroom in each country may differ greatly from the results demonstrated in this research. From this perspective, the generalization of the findings in this research will be limited. Therefore, it is vital for there to be further studies on the comparison of science education in the classrooms in both countries in terms of their implementation of the concepts of scientific literacy and 21st-century competencies. It will also be helpful for further understanding of science education in each country.

Third, the research was based on the most recently published curricula in the two countries. Without the analysis of pervious national science curricula in the two countries, the explanation about the affiliation to any theories of curriculum should be limited to the status of the two countries and based on a relative position between the two countries. This suggests two potential studies in the future: a) research on comparative studies of a series of national science curricula in Finland and China with a historical perspective; b) research on science curricula in more countries, for example, in the US, the UK, and Germany, which may bring more information on the alignment of curriculum theories with various contexts and traditions. In general, the frameworks developed through this research can be applied as analytical frameworks for broader and more in-depth analysis in the future.

Fourth, even if the research stands with a reflection on neoliberalism influences on education, the concepts and frameworks were derived from or within the contexts of neoliberalism. Namely, the framework of scientific literacy has been derived from the PISA science framework, which was developed by the OECD, an organization with a focus on economic development; the revised ATC21S framework was based on the idea of developing citizens who will be useful for future societies, with an ideology of the knowledge society and human capital. The content analysis as the method has limits in reflective of the ideology beneath the frameworks. Therefore, it would be beneficial to use discourse analysis in future studies, particularly concerning the emergence of the ideology of neoliberalism in education.

Finally, the interpretation of the results was basically from the viewpoints that originated in western countries. In the future, more research with an integration of a perspective based on Chinese cultures may contribute to, and bring in, more balanced and varied views on curriculum development.

References

Addey, C., Sellar, S., Steiner-Khamsi, G., Lingard, B., & Verger, A. (2017). The rise of international large-scale assessments and rationales for participation. *Compare: A Journal of Comparative and International Education, 47*(3), 434-452.

Apple, M. W. (1993). The politics of official knowledge: Does a national curriculum make sense? *Discourse: Studies in the Cultural Politics of Education*, *14*(1), 1-16.

Ahtee, M., Lavonen, J. & Pehkonen, E. (2008). Reasons behind the Finnish success in science and mathematics in PISA tests. *Problems of Education in the 21st Century*, *6*, 18-26.

Ananiadou, K., & Claro, M. (2009). *21st-century skills and competences for new millennium learners in OECD countries*. Retrieved from https://www.oecd-ilibrary.org/docserver/218525261154.pdf?expires=1569848179&id=id&accname=guest&checksum=E773FD6EB4401DD72F43FD3A1A6D913D

Autio, T. (2014). The internationalization of curriculum research. In W. Pinar (Ed.), *International handbook of curriculum research* (pp. 17-31). New York, NY: Routledge.

Ball, S. J. (1998). Big policies/Small world: an introduction to international perspectives in education policy. *Comparative education, 34(2)*, 119-130.

Bazzul, J. (2012). Neoliberal ideology, global capitalism, and science education: engaging the question of subjectivity. *Cultural studies of science education*, *7*(4), 1001-1020.

Bazzul, J. & Carter, L. (2017). (Re)considering Foucault for science education research: considerations of truth, power and governance. *Cultural Studies of Science Education*, *12*(2), 435-452.

Bergqvist, E. & Bergqvist, T. (2017). The role of the formal written curriculum in standards-based reform. *Journal of Curriculum Studies, 49*(2), 149-168.

Binkley, M., Erstad, O., Herman, J., Raizen, S., Ripley, M., Miller-Ricci, M., & Rumble, M. (2012). Defining twenty-first century Skills. In P. Griffin, B. McGaw, & E. Care (Eds.), *Assessment and teaching of 21st century skills* (pp. 17-66). Dordrecht: Springer Netherlands.

Blummer, B., & Kenton, J. M. (2014). *Improving Student Information Search*. Retrieved from https://www.sciencedirect.com/book/9781843347811/improving-student-information-search#book-info

Bray, M., Adamson, B., & Mason, M. (2007). *Comparative education research: approaches and methods*. New York: Springer.

Bybee, R., & McCrae, B. (2011). Scientific literacy and student Attitudes: perspectives from PISA 2006 science. *International Journal of Science Education, 33*(1), 7-26.

Carter, L. (2005). Globalization and science education: rethinking science education reforms. *Journal of research in science teaching, 42*(5), 561-580.

Carter, L. (2008). Globalization and science education: the implications of science in the new economy. *Journal of research in science teaching, 45*(5), 617-633.

Chiu, M.-H., & Duit, R. (2011). Globalization: science education from an international perspective. *Journal of research in science teaching, 48*(6), 553-566.

Cho, J. & Trent, A. (2014). Evaluating qualitative research. In P. Leavy (Ed.), *The Oxford handbook of qualitative research*. Retrived from https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199811755.001.0001/oxfordhb-9780199811755-e-012

Crawford, B. A. (2007). Learning to teach science as inquiry in the rough and tumble of practice. *Journal of Research in Science Teaching, 44*(4), 613-642.

Cropley, A. J. (2011). Definitions of creativity. In M. A. Runco, & S. R. Pritzker (Eds.), *Encyclopedia of creativity* (2nd ed, pp. 358-368). San Diego: Academic Press. Retrieved from http://dx.doi.org/10.1016/B978-0-12-375038-9.00066-2

Cuban, L. (2013). Why so many structural changes in schools and so little reform in teaching practice? *Journal of Educational Admin, 51*(2), 109-125.

Cuban, L. (1992). Curriculum stability and change. In P. W. Jackson (Ed.), *Handbook of research on curriculum: a project of the American Educational Research Association* (pp. 216-247). New York: Macmillan Pub. Co.

DeBoer, G. E. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching, 37*(6), 528-601.

DeBoer, G. E. (2011). The globalization of science education. *Journal of Research in Science Teaching, 48*(6), 567-591.

Deng, Z. (2015). Content, Joseph Schwab and German Didaktik. *Journal of Curriculum Studies, 47*(6), 773-786.

Deng, Z. (2018). Contemporary curriculum theorizing: crisis and resolution. *Journal of Curriculum Studies, 50*(6), 691-710.

Ding, B.P. (2015). Science Education in Mainland China. In R. Gunstone (Ed.), *Encyclopedia of Science Education* (pp. 882-889). Dordrecht: Springer Netherlands.

Eisenberg, M., Lowe, C. A., & Spitzer, K. L. (2004). *Information literacy: Essential skills for the information age* (2nd ed.). Westport, CT: Libraries Unlimited.

Elo, S. & Kyngäs, H. (2008). The qualitative content analysis process. *Journal of Advanced Nursing*, *62*(1), 107–115.

European Union, Education and Culture DG. (2008). *Key Competences for lifelong learning: European reference framework*. Luxembourg: Office for Official Publications of the European Communities. Available https://publications.europa.eu/en/publication-detail/-/publication/5719a044-b659-46de-b58b-606bc5b084c1

Fensham, P. J. (2009). The link between policy and practice in science education: The role of research. *Science Education, 93*(6), 1076-1095.

Finnish National Board of Education (2016). *National core curriculum for basic education 2014*. Helsinki: National Board of Education.

Fisher, R. (1991). *Teaching children to think* (Reprinted.). Hempstead: Simon and Schuster Education.

Fullan, M. G. (2001). *The new meaning of educational change* (3rd ed.). New York, NY: Teachers College Press.

Gibbons, M. (2000). Mode 2 society and the emergence of context-sensitive science. *Science and Public Policy, 27*(3), 159-163.

Goodlad, J. I. (1984). *A place called school: prospects for the future*. New York: McGraw-Hill Book Company.

Grek, S. (2009). Governing by numbers: the PISA “effect” in Europe. *Journal of Education Policy*, *24*(1), 23-37.

Hodson, D. (2003). Time for action: Science education for an alternative future. *International Journal of Science Education, 25*(6), 645-670.

Hodson, D. (2011). *Looking to the Future: building a curriculum for social activism*. Rotterdam: Sense Publishers.

Hoskins, B., & Fredriksson, U. (2008). *Learning to learn: What is it and can it be measured?* Retrieved from https://doi.org/10.2788/83908

Hopmann, S. (2007). Restrained teaching: The common core of Didaktik. *European Educational Research Journal*, 6(2), 109-124.

Hopmann, S. T. (2009). Mind the gap: Dewey on educational bridge-building. *Journal of Curriculum Studies, 41*(1), 7-11.

Hsieh, H.-F., & Shannon, S. E. (2005). Three Approaches to Qualitative Content Analysis. *Qualitative Health Research*, *15*(9), 1277–1288. https://doi.org/10.1177/1049732305276687

John-Steiner, V. (2011). Collaboration. In M. A. Runco, & S. R. Pritzker (Eds.), *Encyclopedia of creativity* (2nd ed., pp. 222-225). San Diego: Academic Press. Retrieved from http://dx.doi.org/10.1016/B978-0-12-375038-9.00039-X

Kaya, S., Erduran, S., Birdthistle, N. & McCormack., O. (2018). Looking at the social aspects of nature of science in science education through a new lens. *Science & Education, 27*(5-6), 457-478.

Klafki, W. (2000). The significance of classical theories of *Bildung* for a contemporary concept of Allgemeinbildung. In I. Westbury, S. Hopmann, & K. Riquarts (Eds.), *Teaching as a reflective practice: the German Didaktik Tradition* (pp. 85-107). Mahwah, NJ: Lawrence Erlbaum Associates.

Lähdemäki J. (2019) Case Study: The Finnish National Curriculum 2016—A Co-created National Education Policy. In J. W. Cook (Ed.), *Sustainability, Human Well-Being, and the Future of Education* (pp. 397-422). London: Palgrave Macmillan.

Law, W. (2014). Understanding China's curriculum reform for the 21st century. *Journal of Curriculum Studies*, *46*(3), 332-360.

Levinson, R. (2010). Science education and democratic participation: an uneasy congruence? *Studies in Science Education*, *46*(1), 69-119.

Levinson, R. (2018). Realising the school science curriculum. *The Curriculum Journal, 29*(4), 522-537.

Lin, T., Lin, T., Potvin, P., Tsai., C. (2019). Research trends in science education from 2013 to 2017: a systematic content analysis of publications in selected journals. *International Journal of Science Education, 41*(3), 1-21.

Lincoln, Y. S., & Guba, E. G. (1985). *Naturalistic inquiry*. Newbury Park, CA: Sage.

Ma, X., Jong, C. & Yuan, J. (2013). Exploring reasons for the East Asian success in PISA. In H. Meyer & A. Benavot (Eds.), *PISA, power, and policy: the emergence of global educational governance* (pp. 225-246). Oxford: Symposium Books.

Mason, M. (2007). Critical thinking and learning. *Educational Philosophy and Theory, 39*(4), 339-349.

Mayring, P. (2015). Qualitative Content Analysis: Theoretical Background and Procedures. In A. Bikner-Ahsbahs, C. Knipping, & N. C. Presmeg (Eds.) *Approaches to Qualitative Research in Mathematics Education* (pp. 365-380). Dordrecht: Springer Netherlands.

Millar, R. (2006). Twenty-First Century science: Insights from the design and implementation of a scientific literacy approach in school science. *International Journal of Science Education, 28*(13), 1499-1521.

Ministry of Education. (2017). Number of Full-time Teachers in Primary School by Subject Taught and Educational Attainment. Retrieved from http://www.moe.gov.cn/s78/A03/moe_560/jytjsj_2017/qg/201808/t20180808_344718.html

Musil, C. M. (2009). Educating students for personal and social responsibility. In T. Ehrlich (Ed.), *Civic engagement in higher education: Concepts and practices* (pp. 49-68). San Francisco: Jossey- Bass.

Niemi, H., Toom, A., & Kallioniemi, A. (2016). *Miracle of education: The principles and practices of teaching and learning in Finnish schools* (2nd ed.). Rotterdam: Sense Publishers.

Norris, S. P., & Phillips, L. M. (2003). How literacy in its fundamental sense is central to scientific literacy. *Science Education, 87*(2), 224-240.

OECD. (2011). *Education at a Glance 2011*: *OECD Indicators*. Retrieved from http://dx.doi.org/10.1787/eag-2011-en

OECD. (2013). *PISA draft science framework*. Retrieved from http://www.oecd.org/pisa/pisaproducts/Draft%20PISA%202015%20Science%20Framework%20.pdf

OECD. (2016), *PISA 2015 Results (Volume I): Excellence and Equity in Education*. Retrieved from https://read.oecd-ilibrary.org/education/pisa-2015-results-volume-i_9789264266490-en#page1

Oliva, P. (1997). *The Curriculum: Theoretical Dimensions*. New York: Longman.

Osborne, J. (2007). Science education for the twenty first century. *Eurasia Journal of Mathematics, Science & Technology Education, 3*(3), 173-184.

Osborne, J. (2014). Scientific practices and inquiry in the science classroom. In N. G. t. Lederman & S. K. t. Abell (Eds.), *Handbook* *of research on science education*. (Vol. 2, pp. 579-599). New York: Routledge.

Pantić, N., & Wubbels, T. (2012). Competence-based teacher education: A change from *Didaktik* to Curriculum culture? *Journal of Curriculum Studies*, *44*(1), 61-87.

Prior, L. (2014). Content Analysis. In P. Leavy (Ed.), *The Oxford Handbook of Qualitative Research*. Retrieved from https://www.oxfordhandbooks.com/view/10.1093/oxfordhb/9780199811755.001.0001/oxfordhb-9780199811755-e-008

National Research Council. (2012). *Education for life and work: Developing transferable knowledge and skills in the 21st century*. Washington, DC: The National Academies Press.

Reimers F. M. & Chung C. K. (2016). A comparative study of the purposes of education in the twenty-first century. In Reimers F. M. & Chung C. K. (Eds.), *Teaching and learning for the twenty-first century: educational goals, policies, and curricula from six nations* (pp. 1-24). Cambridge: Harvard Education Press.

Roberts, D. A. (2007). Scientific literacy/ science literacy. In S. K. Abell, & N. G. Lederman (Eds.), *Handbook of research on science education* (pp. 729-780). New York: Routledge.

Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In N. G. Lederman, & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 545-558). New York: Routledge.

Roth, K. J. (2014). Elementary science teaching. In N. G. Lederman, & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 361-394). New York: Routledge.

Roudometof, V. (2016). *Glocalization: a critical introduction*. New York: Routledge.

Ruzgar, M. E. (2018). On matters that matter in the curriculum studies: an interview with Ian Westbury. *Journal of Curriculum Studies, 50*(6), 670-684.

Saari, A., Salmela, S., & Vilkkilä, J. (2014). Governing Autonomy. In W. Pinar (Ed.), *International handbook of curriculum research* (pp. 183-200). New York, NY: Routledge.

Sadler, T. D., & Zeidler, D. L. (2009). Scientific literacy, PISA, and socioscientific discourse: Assessment for progressive aims of science education. *Journal of Research in Science Teaching*, *46*(8), 909-921.

Sahlberg, P. (2015). *Finnish lessons 2.0: What can the world learn from educational change in Finland?* (2nd Ed.). New York: Teachers College Press.

Schriewer, J. & Martinez, C. (2004). Constructions of internationality in education. In G. Steiner-Khamsi (Ed.), *The Global Politics of Educational Borrowing and Lending* (pp. 29-53). New York: Teachers College Press.

Schwarz, B. (2015). A study on professional competence of future teacher students as an example of a study using qualitative content analysis. In A. Bikner-Ahsbahs, C. Knipping, & N. C. Presmeg (Eds.), *Approaches to Qualitative Research in Mathematics Education* (pp. 381-399). Netherlands: Springer.

Sellar, S., & Lingard, B. (2013). Looking East: Shanghai, PISA 2009 and the reconstitution of reference societies in the global education policy field. *Comparative Education*, *49*(4), 464-485.

Sivesind, K., Afsar, A. & Bachmann, K. E. (2016). Transnational policy transfer over three curriculum reforms in Finland: The constructions of conditional and purposive programs (1994 – 2016). *European Educational Research Journal*, *15*(3), 345- 365.

Sjöström, J., Frerichs, N., Zuin, V. G., & Eilks, I. (2017). Use of the concept of Bildung in the international science education literature, its potential, and implications for teaching and learning. *Studies in Science Education*, *52*(3), 165-192.

Steiner-Khamsi, G. (2003). Transferring education, displacing reforms. In J. Schriewer (Ed.), *Discourse formation in comparative education* (pp. 155-187). Frankfurt, Germany: Peter Lang.

Steiner-Khamsi, Gita (2012). Understanding Policy Borrowing and Lending. Building Comparative Policy Studies. In G. Steiner-Khamsi & F. Waldow (Eds.), *World yearbook of education 2012: Policy borrowing and lending* (pp. 3-17). New York: Routledge.

Steiner-Khamsi, G. (2013). What is wrong with the "what-went-right" approach in educational policy? *European Educational Research Journal*, *12*(1), 20–33.

Takayama, K. (2010). Politics of externalization in reflexive times: reinventing Japanese education reform discourses through "Finnish success". *Comparative Education Review*, *54* (1), 51-75.

Terhart, E. (2003). Constructivism and teaching: A new paradigm in general didactics? *Journal of Curriculum Studies, 35*(1), 25-44.

UNESCO (2017). Education for sustainable development goals: learning objectives. Retrieved from https://unesdoc.unesco.org/ark:/48223/pf0000247444

Vahtivuori-Hänninen, S. H., Halinen, I., Niemi, H., Lavonen, J. M. J., Lipponen, L., & Multisilta, J. (2014). A new Finnish national core curriculum for basic education (2014) and technology as an integrated tool for learning. In Niemi, H., Multisilta, J., Lipponen,

L. & Vivitsou, M. (Eds.), *Finnish Innovations & Technologies in Schools: a Guide towards New Ecosystems of Learning* (pp. 33-44). Rotterdam: Sense Publishers.

Villalba, E. (2011). Critical thinking. In M. A. Runco, & S. R. Pritzker (Eds.), *Encyclopedia of creativity* (2nd ed., pp. 323-325). San Diego: Academic Press. http://dx.doi.org/10.1016/B978-0-12-375038-9.00057-1

Voogt, J., & Roblin, N. P. (2012). A comparative analysis of international frameworks for 21st century competences: Implications for national curriculum policies. *Journal of Curriculum Studies, 44*(3), 299-321.

Wahlström, N. (2018). Where is 'the political' in curriculum research? *Journal of Curriculum Studies, 50*(6), 711-723.

Ward, T. B. (2011). Problem solving. In M. A. Runco, & S. R. Pritzker (Eds.), Encyclopedia of creativity (2nd ed., pp. 254-260). San Diego: Academic Press. Retrieved from http://dx.doi.org/10.1016/B978-0-12-375038-9.00181-3

Westbury, I. (2000). Teaching as a reflective practice: what might Didaktik teach Curriculum? In I. Westbury, S. Hopmann & K. Riquarts (Eds.), *Teaching as a reflective practice: the German Didaktik tradition* (pp. 15-39). Mahwah, NJ: Lawrence Erlbaum Associates.

Weniger, E. (2000). Didaktik as a theory of education. In I. Westbury, S. Hopmann & K. Riquarts (Eds.), *Teaching as a reflective practice: the German Didaktik tradition* (pp. 111-125). Mahwah, NJ: Lawrence Erlbaum Associates.

Weber, R. P. (1990). Basic content analysis: *Quantitative applications in the social sciences* (2nd ed.). CA: SAGE Publications.

Willbergh, I. (2015). The problems of "competence" and alternatives from the Scandinavian perspective of Bildung. *Journal of Curriculum Studies, 47*(3), 334-354.

Young, M. (2013). Overcoming the crisis in curriculum theory: a knowledge-based approach. *Journal of Curriculum Studies, 45*(2), 101-118.

Zhang, H., & Gao, Z. (2014). Curriculum Studies in China. In W. Pinar (Ed.), *International handbook of curriculum research* (pp. 118-133). New York, NY: Routledge.

Appendixes

Appendix 1

Coding Agenda for the analysis of scientific literacy

Category	Operational Definition	Code	Identifiable words (example)
Context A set of backgrounds or situations	*Topic* (areas of application) is a theme to classify the backgrounds in which an objective is described.	Health and disease	Health, safe
		Natural resources	Resources
		Environmental quality	Environmental, ecology
		Hazards	Disaster, typhoon, risk situations
		Frontiers of science and technology	Technology
	Perspective includes three levels: "personal" is the situation relating to the self, family, school, and peer groups; "local" is the situation relating to the community or nation; "global" is the situation relating to the life across the world	Personal	Salt, sugar
		Local	Surroundings, built environment
		Global	World, global, ecology
Scientific Knowledge Basic understanding of science from a cognitive perspective	*Content knowledge* Knowledge of the facts, concepts, ideas, and theories about the natural world that science has established (Knowledge of "what" in science)	Physical systems	Force, material, energy
		Living systems	Plant, animal, human body
		Earth and space systems	Sun, star, earth
		Technology and engineering system	Tool, lever, design
	Procedural knowledge Knowledge of the procedures that scientists use to establish scientific knowledge and procedures	Procedural knowledge	Observe, use, how

Category	Operational Definition	Code	Identifiable words (example)
	technologists and engineers to design devices. (Knowledge about “how to do science”)		
	Epistemic knowledge Knowledge of the constructs and defining features essential to the process of knowledge building in science and their role in justifying the knowledge produced by science (Knowledge about “why”)	Epistemic knowledge	Significance, reflect
Scientific Competencies Ability to apply scientific knowledge into specific situations with scientific attitudes	*Explain phenomena scientifically* The ability to apply scientific knowledge in a specific situation, for instance, proposing hypotheses and giving explanations to the scientific phenomenon.	Explain phenomena scientifically	Describe, explain
	Evaluate and design scientific inquiry The ability to describe and appraise scientific investigations and propose ways of addressing questions	Evaluate and design scientific inquiry	Observe, process, information, ask questions, examine, make field trips
	Interpret data and evidence scientifically The ability to analyze and evaluate scientific data, claims, and arguments in a variety of representations and draw appropriate conclusions	Interpret data and evidence scientifically	Analyze, produce, present
	Apply scientific knowledge into practice The ability to apply scientific knowledge to design a device, do hands-on work or for everyday life	Apply scientific knowledge into practice	Act, field trip, design
Scientific Attitudes	*Interest in science* A set of feelings and beliefs about learning or exploring issues that related to science, technology, and engineering	Interest in science	Curious, passionate, interest

Category	Operational Definition	Code	Identifiable words (example)
An expression of favor toward learning and doing science and virtues in scientific research	*Disposition of scientific approaches to inquiry* A rational attitude to the use of scientific methods to investigate material and social phenomena	Disposition of scientific approaches to inquiry	Wonder, based on evidence
	Environmental awareness A concern for the environment and responsible disposition towards the environment	Environmental awareness	Sustainable development, environment(al)
	Self-efficacy and self-concept The confidence in personal abilities to successfully perform a task in science	Self-efficacy and self-concept	Persistent, confident
	Ethics in Science Concerns about the importance of how facts and values interact, critical views on SSIs, and democratic participation in social and political issues, i.e., the use of embryos in research	Ethics in Science	Ethics

Appendix 2

Coding Agenda for the analysis of 21st-century competencies

Category	Code	Operational definition	Identifiable words (example)
Ways of thinking How to think, without practical doing	Critical thinking	The skill to provide a judgment based on the evaluation, analysis, synthesis, and interpretation The skill promotes thinking or valuing ideas, facts and methods from different perspectives, usually from an opposite perspective (Mason, 2007; Villalba, 2011)	Critical thinking, wonder, ask questions
	Creative thinking	Imaginative or inventive skills, which involves the generation of new ideas (Fisher, 1991) and the production of relevant and effective novelty (Cropley, 2011)	Innovate, find different alternatives and solutions
	Using metacognition (Learning to learn)	Using metacognition refers to the ability to pursue and persist in learning, to organize one's learning, reflecting on the learning, and adjusting the learning process, including through effective management of time and information, both individually and in groups (Hoskins & Fredriksson, 2008). Learning to learn refers to the competency for lifelong learning.	Self-image as learners, regulate study by oneself, reflect
Ways of working How to work and process issues in practice	Inquiry	A systemic action process in investigating, collecting and examining issues in a situation	Acquire, process, evaluate, appraise information
	Problem-solving	A systemic process whereby the person overcomes obstacles and moves from a start state to the goal state (Ward, 2011)	Problem-solving, solutions to an everyday problem
	Collaboration	A competency in studying or working with one or more individuals in groups, where participants help and support each other with complementary skills, interacting to create a shared understanding that none had previously possessed or could have come to on their own (John-Steiner, 2011)	Acting in a group, collaborate
	Communication	The competency of using words, sounds, signs, or other behaviors to express or exchange information, such as ideas,	Present information, exchange ideas, communicate

Category	Code	Operational definition	Identifiable words (example)
		thoughts, and feelings, to someone else with respect or listening to other people	
Tools for working The comprehension and application of tools for thinking and working	ICT (technological tools)	The ability to recognize, locate and use information needed for a specific context efficiently and effectively via information and communication technology	ICT environments, video
	Information Literacy (Concepts)	The ability to recognize, locate, and use information needed for a certain context efficiently and effectively (Eisenberg, Lowe & Spitzer, 2004). This code includes the ability to use terms in science to explain or describe phenomena.	Explain phenomena using terms in science
Living in the world The virtue of morals, attitudes, belief, and flexibility of living as human beings	Citizenship	The competency in participating in civic activities/ in society-related activities. It includes, but is not limited to environmentally-friendly activities, the economy or society development activities, energy-saving activities	Society, responsibility
	Life and career	The competencies in understanding unstable situations, settling the challenges in a changeable world with intentions for an ethical, rational and moral life	Well-being
	Personal and social responsibility (cultural awareness and competency)	The competency in tolerance and respect for people different from themselves and of other backgrounds, for example, in race, ethnicity, lifestyles It includes cultural and global awareness and sensitivity and personal identification (Musil, 2009). It manifests in aspects of culture, humanity, and morality in science education.	Respect others